NEW FUNCTIONALITY FOR BEAM DYNAMICS IN ACCELERATOR TOOLBOX (AT)

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Abstract

Accelerator Toolbox is a widely used code for beam dynamic simulations based on Matlab. To continue the development of the code in a collaborative manner, a Source-Forge project and SVN repository called *atcollab* has been established. Here we describe the contributions to *atcollab* from the ESRF beam dynamics group. Additional modules have been developed: general matching (*atmatch*), improved plotting (*atplot*), Touschek lifetime computation via the Piwinski formula, nonlinear dynamics computations such as resonance driving terms, improved reporting of lost particles and improvements and additions to the integration routines. One example of the latter includes diffusion due to quantum fluctuations. Modeling of collective effects may now be performed using pass methods representing a variety of impedance models. Finally, routines to replace the full ring with a compact representation have been developed, facilitating studies in which many turns and many particles are required.

INTRODUCTION

Accelerator Toolbox (AT) is a Matlab [1] based tool box for accelerator simulation originally created by Andrei Terebilo during the late 1990's at SLAC [2,3]. The latest release of AT from SLAC is 1.3. AT is widely used at accelerator facilities around the world. We describe the status of the developments made by the ESRF beam dynamics group, outlining our approach and some of the additions since AT 1.3. We have made an effort to maintain backwards compatibility throughout these changes.

WORKING WITH LATTICE STRUCTURES

Consistent with the original design of AT, a storage ring lattice is a Matlab structure where each element contains a link to a pass method[1] together with the relevant data to describe the element. Particles may then be tracked through the lattice structure using the function called *atpass* which is a compiled C language Mex Function for purposes of speed.

Element Creation Functions

Element creation functions exist to aid in the creation of a valid lattice structure. Previous versions of AT included many of these, but within a global variable structure. These have been modified to allow direct output of the lattice elements. As an example,

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[1] A pass method, or integrator is a function that maps initial phase space to final phase space in an element.

QF=atquadrupole('QF1',0.94,0.39,'QuadMPoleFringePass') produces a quadrupole element structure with length 0.94 m and $k = \frac{1}{B\rho}\frac{\mathrm{d}B_y}{\mathrm{d}x} = 0.39m^{-2}$ using the pass method QuadMPoleFringePass. These elements may then be strung together to create a lattice structure.

Class Field

The field 'Class' has been added to each element to facilitate element finding. The classes are 'Drift', 'Bend', 'Quadrupole', 'Sextupole', 'Multipole', 'ThinMultipole', 'Wiggler', 'KickMap', 'RFCavity', 'QuantDiff', 'Aperture', 'Monitor', 'Corrector', 'Solenoid', 'Matrix66', 'RingParam'. As an example, the indices of all sextupoles may be simply found using the command 'indsext=findcells(ring,'Class','Sextupole')'. The 'RingParam' element may contain global parameters describing the ring such as the electron energy or the ring periodicity, in case only one period is represented in the structure.

Lattice Manipulation Functions

We create functions to make changes to a lattice. Examples include misalignments and multipole errors. Additional function for setting elements properly include functions for setting cavities, turning radiation on and off, etc. The element creation functions output a lattice element directly. The lattice manipulation functions work directly with lattice structures. Working this way, rather than with a global variable THERING or FAMLIST as in AT 1.3, allows multiple ring structures to be stored simultaneously and more easily compared.

Plotting

A new plotting routine has been developed called *atplot*. It allows the plotting of arbitrary functions around the ring, together with the lattice synoptic. Examples are shown in Fig. 1 and 2. In Fig. 1, we see a plot of the varying dipole strength in sliced dipoles, together with the $\mathcal{H}_x$ function. This visualization allows understanding of how emittance may be minimized. In Fig. 2, we plot the geometric Hamiltonian driving terms throughout a lattice cell for the ESRF upgrade lattice. These have been computed using code from Elegant [4] interfaced to AT via MEX.

Matching

The function *atmatch* [5] allows general linear and nonlinear matching of an AT lattice structure. For optics matching the routine uses the function *atlinopt* (with a single call for all matching conditions), however generic Matlab functions may be used both to define variables (matching knobs) or conditions to be achieved, such as emittance reduction,
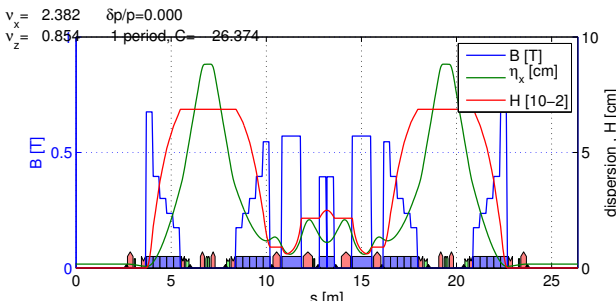
Figure 1: Plot of dipole field and $\mathcal{H}_x$ function for ESRF upgrade lattice.
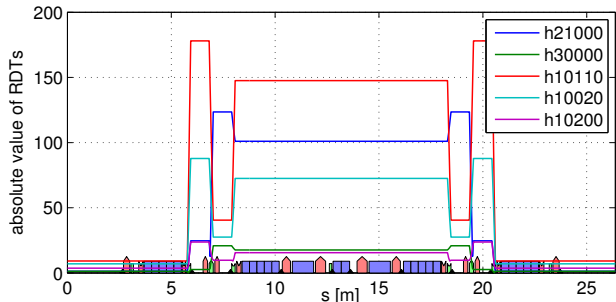

Figure 2: Plot of geometric Hamiltonian driving terms for ESRF upgrade lattice.

tunes, or more complex quantities. One may also specify constraints on the variables during the optimization procedure, a very relevant feature for non-linear optimizations.
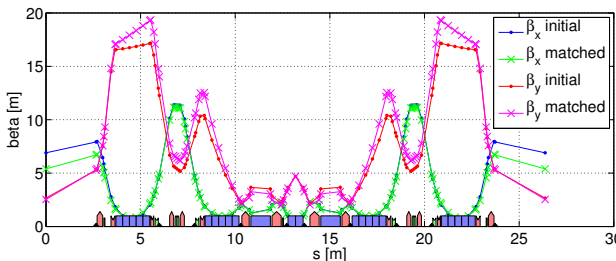

Figure 3: Varying of the β functions using *atmatch*.

The algorithm used for the minimization may be Matlab *fminsearch* or *lsqnonlin*, but extension to other algorithms is straight forward. As examples of the use of *atmatch*, we show in Fig. (3) and (4) variation of the beta functions and an example of matching an orbit bump of varying amplitude. Currently *atmatch* allows only the closed rings to be matched, but the implementation of initial conditions for transfer lines is under study.

Fast Ring Function

The function *atfastring* has been written to create a fast tracking lattice from a given full lattice structure. It produces two ring structures, one with radiation effects and another without. The fast ring contains the following elements: a cavity, a 6x6 one turn map matrix and a non-linear
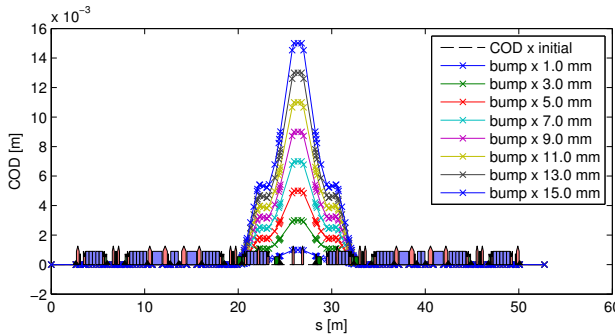

Figure 4: Varying an orbit bump using *atmatch*.

element simulating linear chromaticities and tune shift with amplitudes. The fast ring with radiation contains the same elements, but in addition a diffusion element, and a damping matrix are included. In addition to use in collective effects studies described earlier, the fast ring is also useful for spin depolarization studies [6].

PHYSICS DEVELOPMENTS

Additional physics modules are being developed and added to the *atcollab* repository. Some of these take the form of additional pass methods or improvements to the existing ones. Others are functions that take outputs of existing linear or non-linear tracking.

Touschek Lifetime with Piwinski Formula

One example is the calculation of Touschek lifetime via the Piwinski formula [7]. The function is called *TouschekPiwinskiLifetime*: given the momentum acceptance as a function of the position in the lattice, the function implements the equations in [7] for a flat beam. The effect of errors, apertures and RF voltage must be included beforehand in an appropriate computation of the momentum acceptance.

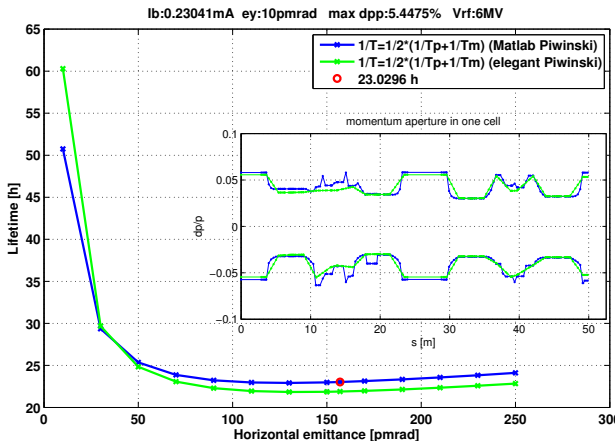Figure 5 shows an example comparison to the code Elegant [4] giving satisfactory agreement.

Figure 5: Comparison between Touschek lifetime using Piwinski in AT and computation using Elegant.

Impedance and Multi-particle Tracking

The possibility of performing multi-particle tracking simulations including wakefields was recently included into AT in view of the design needs for the ESRF upgrade program. The lattice is in this case modeled using a simple one turn map generated by the fast ring function. The wakefields can either be analytically derived from resistive wall or resonator formulas or loaded from an external file, the latter allowing modeling of arbitrary wake functions. The implementation is similar to the one used in the code HEADTAIL [8], i.e. the bunch is sliced longitudinally and the effect of leading slices on the trailing ones is computed and applied at each turn. A full benchmarking against HEADTAIL was performed including synchrotron radiations and quantum diffusion. Fig. (6) shows an example of a longitudinal broadband resonator to model the microwave instability threshold which is observed in this case at approximately 4.0e11 electrons per bunch. An excellent agreement was found between the two codes in all the cases tested.
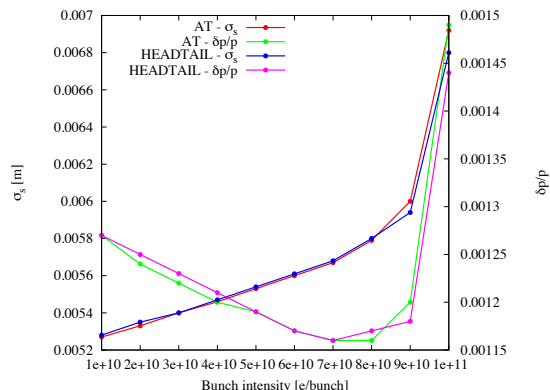

Figure 6: Calculation of bunch length and energy spread, comparing multi-particle AT code with HEADTAIL code.

Particle Loss History

The *ringpass* function has been modified to facilitate particle loss studies. When a particle is lost on a physical aperture, the element and turn number is recorded along with the recent orbit history. This feature has been used in beam loss studies for the ESRF current and upgrade lattice [9, 10] .

Quantum Diffusion

We have implemented an element to include the effects of quantum diffusion due to radiation [11]. The element may be added as a single kick which will have a random magnitude, but the correct standard deviation to produce the equilibrium electron beam when acting in conjunction with radiation damping. Using the global diffusion matrix $\bar{D}$ Cholesky decomposition is applied to write $\bar{D} = L^T L$. One then applies L^T to a random kick with unit standard deviations in each of the phase space coordinates. Figure 7 shows an example of the use of the quantum diffusion element in a lattice with radiation in the dipoles. Many particles are tracked for multiple damping times, until equilibrium is reached.
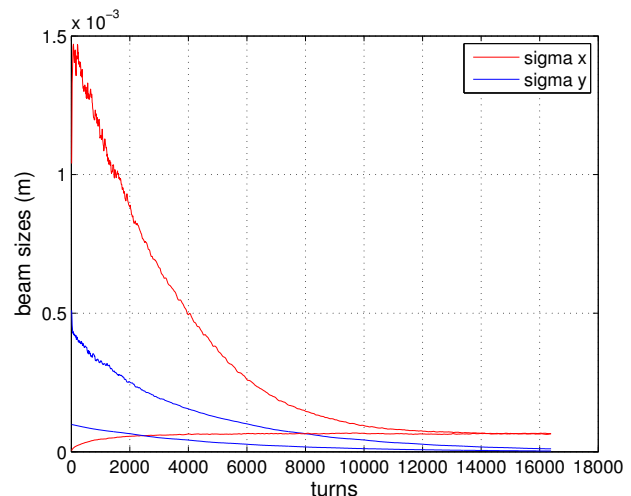

Figure 7: Evolution of beam sizes with quantum diffusion element for the uncoupled ESRF lattice. Two different sets of initial conditions are used, showing evolution to the same final equilibrium. In these simulations, 2048 particles were tracked for 16,384 turns.

COLLABORATION

These developments are available in an SVN repository on Sourceforge under the project name of *atcollab*. This can be found at the URL http://sourceforge.net/projects/atcollab/. A mailing list exists for communications and discussion.

CONCLUSION

We have described some of the recent developments by the ESRF beam dynamics group to the AT code which is hosted under the Sourceforge project *atcollab*. We foresee continued development and collaboration and encourage more users of the code to get involved with testing and development.

ACKNOWLEDGMENTS

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